

Comparing survey methods for monitoring vegetation change through time in a restored peatland

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Abstract Monitoring is an essential step to assess vegetation trajectories post-restoration and ultimately evaluate success. In this paper, we compare two monitoring methods, the line-point intercept (LPI) and the permanent plot (PP) methods, for evaluating plant recovery of a restored cut-over peatland (8.5 ha), following a “moss layer transfer technique”. We used the LPI method to estimate covers (from frequency measures) for each plant species using a systematic grid of approximately 5,700 points (every 3 m × 5 m). In parallel, 43 PP (3 m × 8 m) were established and used to evaluate plant covers. The post-restoration recovery of vegetation was assessed against a reference ecosystem encompassing the variation in species cover from natural undisturbed peatlands in the same region. For all plant groups considered, the LPI consistently showed higher cover estimates than the PP method. Discrepancy between the two methods was particularly evident for the

Ericaceae group. A complementary sampling method, the line-intercept (LI), showed strong correlations with the visual estimations of Ericaceae covers (akin to PP), suggesting an overestimation from the LPI method. Most life form groups of the restored peatlands are developing a structure similar to the regional reference ecosystem 8 years post-restoration with the herb group being still most dissimilar. Indeed, when analyzing the temporal evolution of the different key peatland plant components, several are within the range of regional abundance values or moving positively towards range of cover abundance of the reference system such as *Sphagnum* cover, a key peat-accumulating plant group.

Keywords Sampling methods · Line-point intercept method · Permanent plots · Line-intercept method · Vegetation recovery · Restoration success

Introduction

Ecological restoration aims to bring back functions and structures of degraded ecosystems which are present in the same type of natural ecosystems of a given region, called the reference ecosystem (Egan 2001). In the case of northern peatlands, peat-accumulating mosses are the primary element to reintroduce if one aims at restoring the most characteristic function of a peatland, being its capacity to accumulate carbon through time (Rochefort 2000). It

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is often difficult to appraise restoration success, because it requires clearly defined goals associated with an accurate monitoring program (Zedler 2007). In that respect, we defined restoration success for this particular study as the colonization of the industrial site by the main regional peatland species to reach a development in abundance within the cover range of a reference ecosystem. However, the choice of the sampling method used for vegetation monitoring can influence restoration success assessment (Korb et al. 2003).

Numerous sampling methods exist for monitoring plant cover or diversity. The most common ones can be classified in two categories: the methods using lines or transects, and those with plots or quadrats (Myers and Shelton 1980). Among the line methods, the line-point intercept (LPI) method measures species frequencies by recording all species hit by a vertical rod placed at pre-determined systematic intervals along the line or a grid (Bonham 1989). Another method using line, the line-intercept method (LI), measures the length of the projected foliage of each species along the line (Canfield 1941). Generally, line methods are assumed to approximate plant covers but may lead to over-estimation. They can involve a high degree of spatial autocorrelation and require a large sampling effort (Mueller-Dombois and Ellenberg 1974; Goslee 2006; Stohlgren 2007).

Among the plot methods, the permanent plot (PP) approach consists in installing plots in the field at known locations and surveying them repeatedly at specific time intervals. Species cover is then evaluated to the nearest percentage or in wider cover classes such as the original or adapted Braun-Blanquet scale (Londo 1976). Plots can be placed randomly to minimize spatial autocorrelation effects (Goslee 2006). Otherwise, they can be placed systematically when the vegetation is homogenous or following a stratified design when there is spatial variation. The size of the survey plots is adjustable to the vegetation (type and size of plant species), the time available for the monitoring and the required precision for cover estimates (Mueller-Dombois and Ellenberg 1974).

The return of different structures and functions of restored peatlands in eastern Canada have recently been assessed for hydrology (Petroni et al. 2003; Shantz and Price 2006), carbon sequestration (Waddington and Warner 2001; Lucchese et al. 2009), fauna and flora diversity (Mazerolle et al. 2006; Poulin et al.

2012), and microbiological activity (Andersen et al. 2006). In this paper, we focus on assessing the return of the vegetation structure and abundance 8 years post-restoration. Due to the presence of both mosses and vascular plants, peatlands are good model ecosystems to evaluate sampling methods. Our objectives were first methodological. We aimed (1) to evaluate the influence of survey methods (LPI and PP methods) on the assessment of plant trajectory after restoration, and (2) to determine the impact of reducing the sampling effort on plant frequency of occurrence, in order to optimise monitoring. In addition to methodological concerns, we aimed to assess the success of the vegetation recovery against a regional reference ecosystem.

Methods

Site description

The Bois-des-Bel (BDB) peatland (47°58'N, 69°26'W) extent is 189 ha, of which horticultural peat was extracted over a section of 11.5 ha from 1972 to 1980 (Fig. 1a). The residual peat deposit was approximately 2 m deep and a detailed survey conducted in 1995 showed that abandoned surfaces were sparsely colonized by vegetation, and this, still 15 years after peat extracting activities stopped (Poulin et al. 2012). In 1999, we initiated a restoration project on 8.4 ha of the peat extracted section. A zone of 3.1 ha was left unrestored (see Lavoie et al. 2001 for detailed site description).

Restoration of the site by the “*Moss layer transfer technique*”

Restoration of the site was carried out in fall 1999. The restoration procedures were: (1) surface preparation to level the peat fields as well as to break up the dry crust at the soil surface in order to improve contact between soil and plant diaspores; (2) construction of peat berms along topographic gradient for better water distribution (Fig. 1b); (3) transfer of plant diaspores including *Sphagnum* fragments collected in a nearby natural peatland (destined to become an industrial park): the upper 10 cm of vegetation was cut using a rototiller, collected and spread mechanically on the residual peat surfaces at a ratio of 1:10 (1 m² of collected material

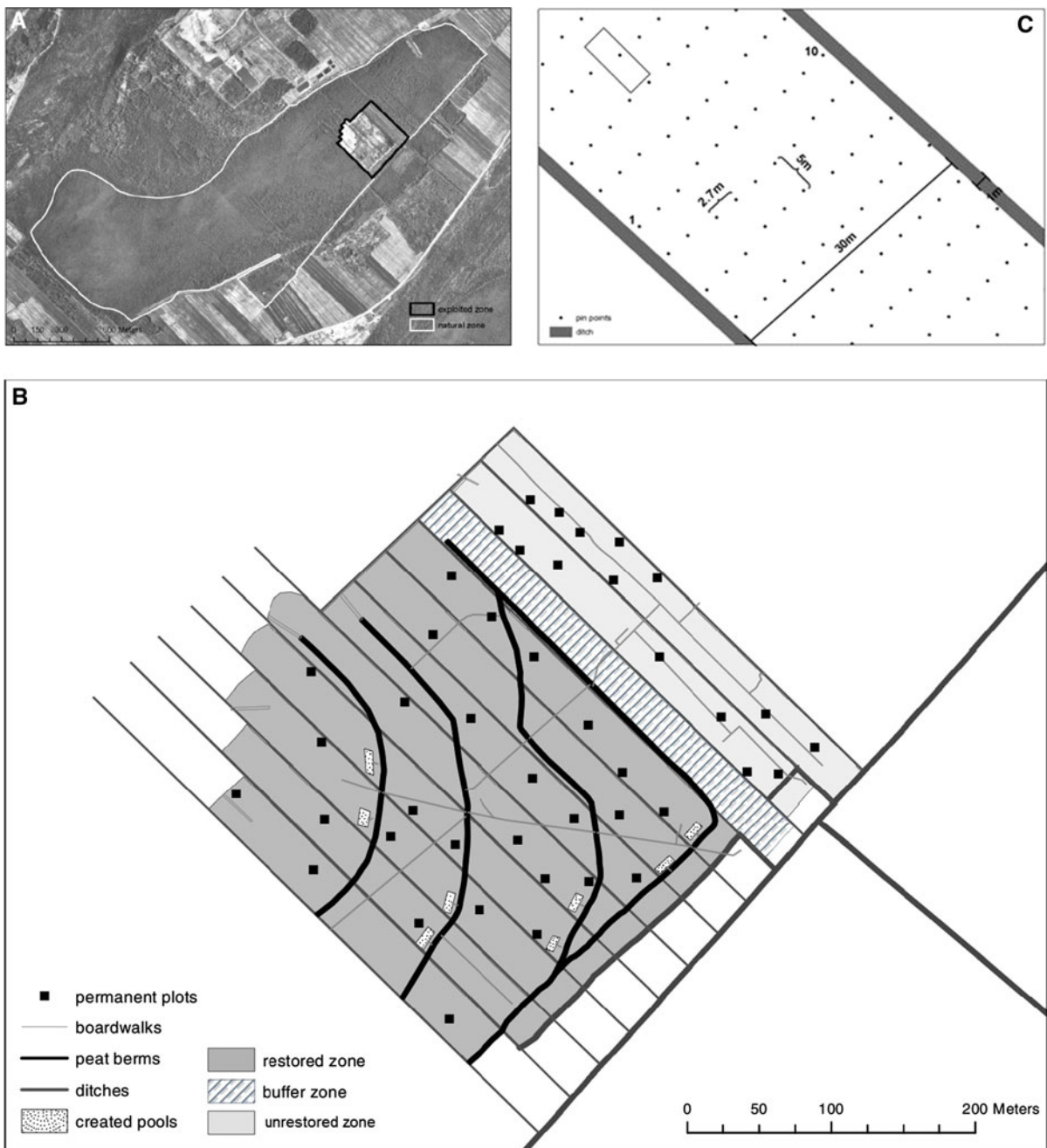


Fig. 1 **a** Aerial view of the intact and peat extracted zones of BDB peatland. The photograph was taken in 2001; **b** schematic representation of the experimental site, illustrating the location of peat berms, board walks, ditches and peat fields which were restored or left unrestored. The approximate location of the 43

PPs is also shown; **c** close view of a section of a peat field bordered by two ditches and where point intercepts are shown as well as one PP. For more details on hydrology of the site, see Shantz and Price (2006)

spread over every 10 m² of the restoration site); (4) spreading of a straw mulch on the introduced vegetation to improve micro-climatic conditions and

protect plant fragments from desiccation; (5) blocking of the drainage ditches to retain water; (6) addition of a phosphorus fertilization (150 kg/ha), in June of the

following summer. Further details are shown at www.gret-perg.ulaval.ca and in the book chapter of Graf et al. (2012).

Vegetation sampling

From start, two long term monitoring programs were used, aiming generally at two different goals: a LPI survey done systematically over the whole site to assess spatial success/failure and a PP approach aiming more at the long-term temporal changes of the plant communities based on the findings of Belsky (1985) that PP was the best long term monitoring approach to track changes through time of grazing impacts by great herbivores. As flat industrial restored peatlands do not show obvious ecological gradient, we did not use gradient-directed transects (Parker et al. 2011). Twenty-meter bands at the beginning and at the end of each peat field were excluded from the surveys to avoid edge effects. We grouped species by life forms: (1) moss layer (including liverworts, hornworts and *Sphagnum* species—lichens were also considered in this group but exclusively the species growing on soil surface—fruticose); (2) herbaceous plants; (3) Ericaceae (including shrubs and creeping shrubs); and (4) shrubs and trees (ligneous plants other than Ericaceae). Each group corresponds generally to a stratum of increasing height. Species taxonomy follows Anderson et al. (1990) for mosses, Anderson (1990) for *Sphagnum* species, Brodo et al. (2001) for lichens and Flora of North America Editorial Committee (1993+) for vascular plants.

The line-point intercept method

We used the LPI method (Bonham 1989) to detect the presence or absence of plant species over the entire site. More precisely, every 5 m, a perpendicular line was set across the entire width of the peat field (30 m), and along this line, 10 equidistant points were surveyed, i.e. one every 2.7 m (Fig. 1c). At each sampling point, all plant species intercepted by a vertical rod or by its upward projection were recorded. The surveys were always conducted in July, once prior to restoration (1999) and every 2 years post-restoration (2001, 2003, 2005, and 2007). Total frequency for each species was calculated as the number of hits relative to the total number of points sampled, which was on average 4,450 for the restored zone and 1,225

for the unrestored zone (varied slightly from year to year due to spatial inaccuracy when moving the lines). Frequency was also calculated for each plant group (life form).

The permanent plot method

A total of 43 PPs were installed at the site: 28 in the restored zone and 15 in the unrestored zone (Fig. 1b). Each plot measured 3 m × 8 m. Cover of plant group (Ericaceae, Herbs, Trees and Shrubs) was estimated at the plot scale with a modified Braun-Blanquet scale where 0 = 0 %, 0.5 < 1 %, 1 = 1–10 %, 2 = 11–25 %, 3 = 26–50 %, 4 = 51–75 %, 5 = 76–100 %. The median of these cover classes was used to estimate mean vegetation cover. To diminish subjective bias in cover estimation, all observers calibrated their visual estimation with templates and compared among themselves every day. Also, six circular sub-plots of 70 cm in diameter (0.38 m²) were systematically placed within each plot for estimating the moss layer cover and the vegetation cover at the species level. Indeed, moss cover cannot be visually easily assessed over large plots and averaging small sub-plots cover has proved an accurate method. On the other hand, vascular plant structure would be fragmentary at the sub-plot and was consequently assessed at a larger plot level. However, from the 6th year post-restoration, only four random chosen sub-plots were used to estimate the cover of vascular plant at the species level because of the homogeneity within plots. Based on 20 years of survey experiences in open peatlands, we came to the conclusion that different observers can describe plant cover with this following levels of accuracy: 1 % when the cover is estimated between 1–10 and 90–100 %; to the nearest 2–3 % cover between 10–20 and 80–90 %; to the nearest 5 % for cover between 20 and 80 %. Species cover per plot was calculated from the mean of covers in the sub-plots. Senescent mosses or those partially infected by fungi or algae were not recorded. The cover of *Polytrichum strictum* was estimated when the moss was fully hydrated and expanded. When dry, the moss was sprayed with water before cover estimation to avoid bias caused by appressed dry leaves. For intermingled small mosses and liverworts within the moss carpet, the cover was estimated after having gently untangled the mosses. The PPs were surveyed yearly, in late August.

Sampling techniques for Ericaceae

Eight years post-restoration, we used another sampling method on Ericaceae species seeking to understand the discrepancies revealed in our study between the LPI and the PP methods. We adapted a LI method initially developed for measuring trees and shrubs cover (Canfield 1941). The method consists in stretching a measuring tape (line) between two points and to measure the length of the projected foliage of the target species situated along the tape. Among four randomly selected peat fields (three in the restored zone and one in the unrestored zone) we placed three plots of 4 m² at random for the LI measurements. Each plot was divided into four 1 m × 1 m sub-plot (36 sub-plots in restored zone and 12 sub-plots in unrestored zone; Fig. 2). A measuring tape was displaced every 25 cm from one side to another of the sub-plot. On each line, the projected foliage length was recorded for each ericaceous species. Where foliages of different species overlapped, each individual plant species was measured separately. For each sub-plot, the total length for each species divided by the total length of the five lines (5 m), multiplied by 100, is expressed as percent cover for each species. For comparison, the total percent cover of each ericaceous species was also visually estimated in each sub-plot. The correspondence between the two estimates was evaluated with Pearson correlations.

Reference peatland ecosystem

In the last year of monitoring, we surveyed seven *Sphagnum*-dominated peatlands in the region (distributed over 700 km²) surrounding the study site to build a reference ecosystem encompassing the variation in species cover for natural undisturbed peatlands (SER 2004). Ten circular quadrats of 70 cm in diameter (0.38 m²) were sampled along 1-km transects, crossing each peatland (Gignac et al. 2004). The cover of each species was estimated as above for PP.

Sampling effort

In our study, the LPI method was an extensive method, spatially covering the whole site and involving a large number of lines and points. Reducing the sampling effort to diminish cost can have important consequences on plant abundance and cover estimates, as

well as misestimating species diversity (Levin 1992; Stohlgren 2007). We explored the effect of reducing the sample size on the total frequency of occurrence for each plant group across years. A bootstrapping technique (Efron and Tibshirani 1993) was used to analyse how reducing the number of lines for the Line Point Intercept database affected the variance of the mean frequency of occurrence for each plant group. We used the empirical data set to randomly generate samples of desired size, here fractions of 90–80–70–60–50–40–30–20–10 % of the initial number of transects. For each fraction, 1,000 simulations were conducted and each time, a frequency of occurrence for each plant group was calculated. The mean frequency of occurrence and its variance were thereafter calculated for each plant group. All years were analysed separately. The eighth year was not evaluated as we had already applied the optimisation results to last year sampling. All simulations were conducted with SAS (version 8.0; SAS Institute Inc., Cary, NC).

Results

Vegetation cover estimates

The LPI method measures frequencies of occurrences, but the method can also be used as an approximation for plant covers, leaf areas or plant biomass (Jonasson 1988). We therefore use the terms percent cover or cover estimates to designate data stemming from both LPI and the PP methods. For all plant groups considered, LPI showed higher cover estimates than PP (Fig. 3). Following, a more detailed analysis of each plant group is presented along with the cover estimate of some key species (Fig. 4) to help interpret the differences in estimates of the monitoring methods.

Moss layer

According to LPI, the estimated moss layer cover increased rapidly from 5 % pre-restoration to 69 % 2 years post-restoration (Fig. 3). Afterwards, the cover of moss layer species kept increasing but at a slower rate to reach 82 % 6 years post-restoration. Covers estimated with PP followed the same general pattern in the first year, but from 2 to 4 years after restoration, the increase in bryophyte cover estimates

Fig. 2 Sketch of a plot used for the complementary measurements of the Ericaceae cover and consisting in a LI method and a visual estimation. The entire *plot* consists in four *frames* (A–D) serving for visual estimation and also divided in five *lines* for linear intercept measurements; details of a *line* is shown below

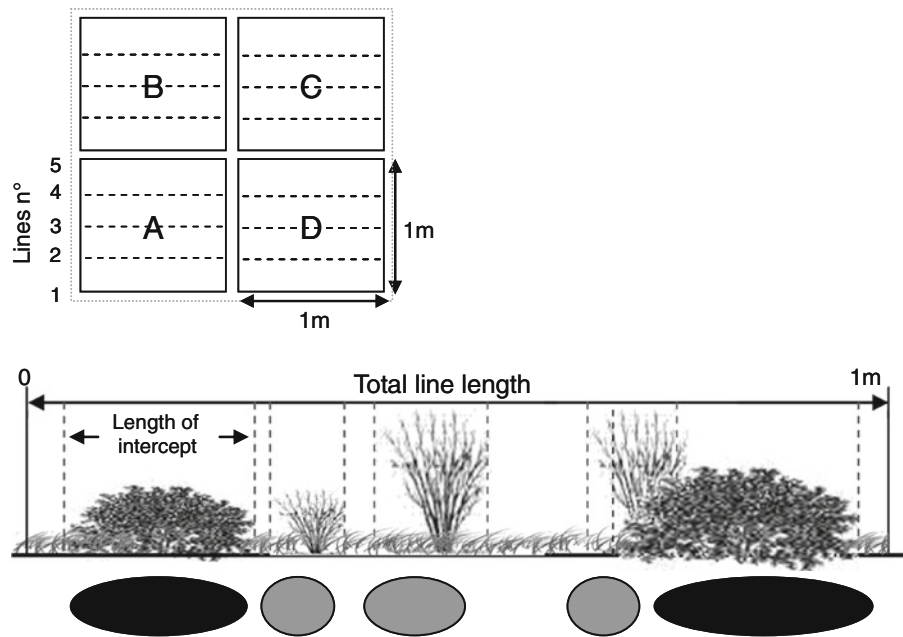
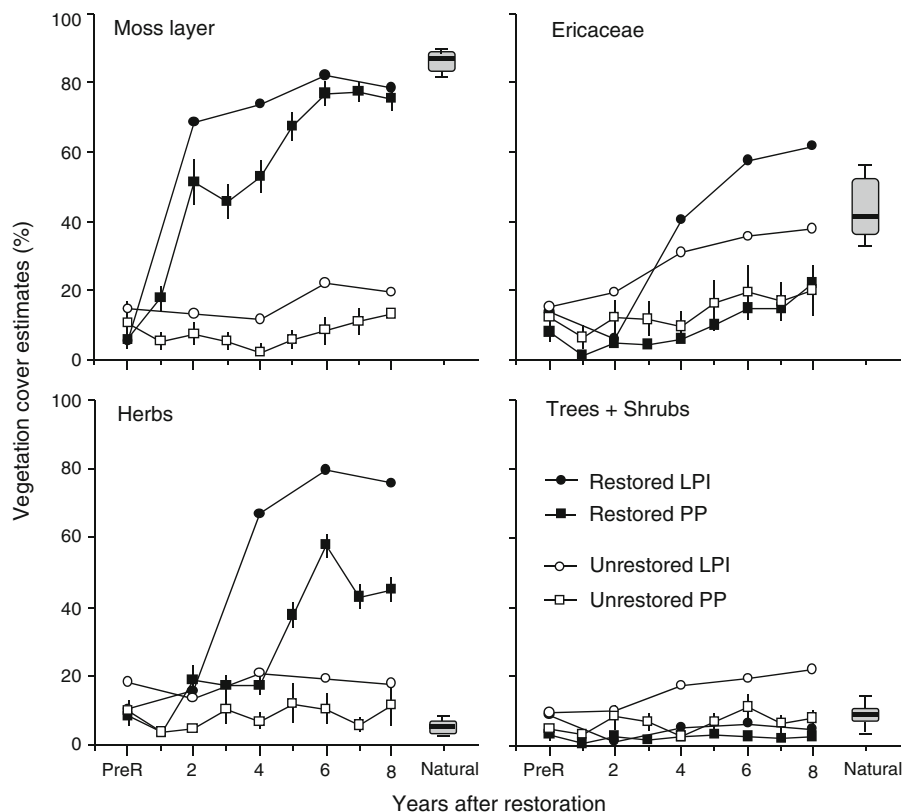


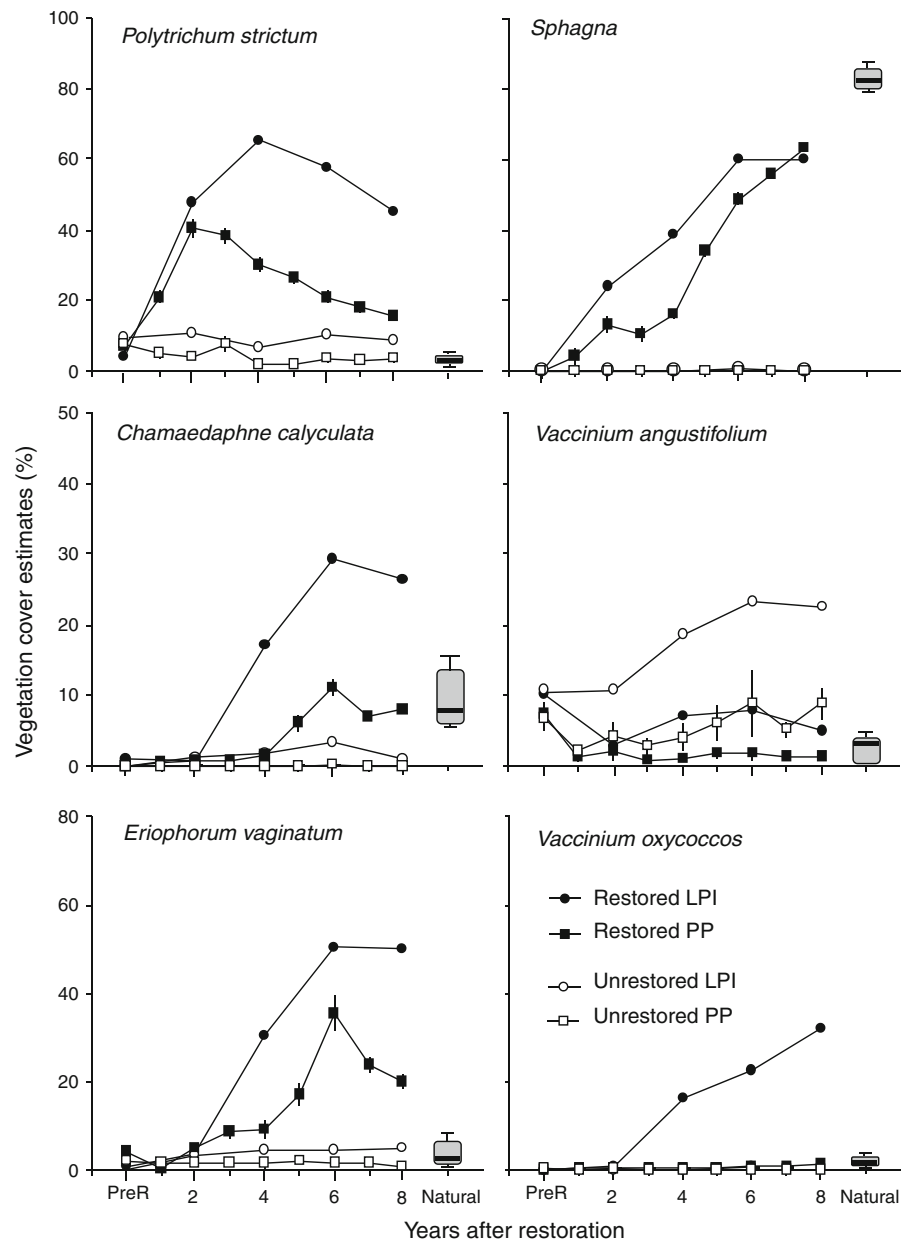
Fig. 3 Cover estimates for the different plant groups from the year prior to (PreR) and after restoration. Values are mean percentages measured with the LPI method or mean percentages \pm SE measured with the PP method at the plot scale (8 m \times 3 m) calculated from the median of each modified Braun-Blanquet scale. *Box-plots* represent the range of vegetation covers observed in the regional natural peatlands surrounding the site ($N = 7$), with first quartile, median (black *trait*), third quartile, smallest observation (down “*whisker*”) and largest observation (up “*whisker*”). Moss layer includes mosses and lichens



was less pronounced than with the LPI. Still, with PP monitoring, it reached 77 % 6–8 years post-restoration; a picture very close to the estimates from LPI.

The moss layer cover remained low in the unrestored zone according to both survey methods: averaging 15 % for LPI and around 8 % for PP.

Fig. 4 Cover estimates for some selected species from the year prior to (PreR) and after restoration. Values are mean percentages measured with the LPI method or mean percentages \pm SE measured with the PP method taken at the sub-plot scale (six or four sub-plots of 0.38 m²). Box-plots represent the range of vegetation covers observed in the natural peatlands surrounding the site ($N = 7$), with first quartile, median (black trait), third quartile, smallest observation (down “whisker”) and largest observation (up “whisker”). *Sphagnum* sp. and *P. strictum* are bryophytes, *E. vaginatum* is an herb and *C. calyculata*, *V. angustifolium* and *V. oxycoccus* are ericaceous species



To understand the cover signature of the moss layer, we looked at the recovery dynamic of *Polytrichum strictum* (Hair cap moss) and all *Sphagnum* species pooled together (Fig. 4). With LPI, cover estimates for *P. strictum* increased steadily for the first 4 years post-restoration to reach 65 % (Fig. 4) and then decreased to 45 % 4 years later. On the other hand, its cover estimated with PP peaked at only 40 % 2 years following restoration and started a steady drop

down to 16 % 7 years post-restoration. In the unrestored zone, the values of *Polytrichum* cover fluctuated slightly but remained under 11 % for both sampling methods.

A *Sphagnum* carpet developed steadily to 60 % 6 years post-restoration (Fig. 4), remaining constant 2 years later according to LPI or slightly increasing to 63 % according to PP. Estimations were most different between the two methods in the fourth years

following restoration. Both sampling methods showed that no *Sphagnum* colonized the unrestored zone during the whole monitoring period.

Ericaceae

Cover estimates of Ericaceae were nearly the same pre-restoration and the 2 years following restoration as measured by both methods (Fig. 3). From the third year though, the two monitoring methods showed a different pattern of evolution in cover estimates (Fig. 3). A sharp increase in Ericaceae was measured by LPI from the second year of restoration where estimates rose steadily from 6 to 62 % 8 years post-restoration. On the opposite, the increase rate of the cover estimates was low when assessed with PP: from 4 % in the second year to only 22 % 8 years post-restoration. A similar discrepancy is also noted in the unrestored zone but to a lesser extent.

To understand the discrepancies between the two methods for ericaceous shrub cover (1) we selected and illustrated graphically certain ericaceous species with the largest deviations of their cover estimates (Fig. 4), and (2) we used a complementary sampling method for comparing visual estimation of cover within plots against LI methods (see “Methods” above).

(1) Analysing results of LPI and PP of the ericaceous species being most different in cover estimates, it is noted that *Chamaedaphne calyculata* and *Vaccinium oxycoccos* had very low cover before restoration until the third to fourth year post-restoration (Fig. 4). Thereafter, the cover of these two species increased sharply with LPI, reaching 29 % for *C. calyculata* and 23 % for *V. oxycoccos* the sixth year. PP detected a lower cover increase for *C. calyculata* with a maximum of 11 % in the sixth year post-restoration, and only a slight cover for *V. oxycoccos*. In the unrestored zone, the cover values stayed below 4 % with the two methods for both species. For *Vaccinium angustifolium* differences between the two methods were noticeable in the unrestored zone mainly. With LPI there was a continuous increase from the year before restoration to the sixth year (23 %), whereas the estimations were variable from year to year and low (9 %) with PP.

(2) With the complementary sampling method of Ericaceae (Fig. 2), the visual estimations of covers (akin to visual estimations done in PP) showed rather strong correlations with the LI (Fig. 5). Significant correlations ranging from 82 to 97 % were found for six of the seven species investigated. Only *V. oxycoccos*, which has a very different morphology from the other ericaceous species showed a weak and non-significant correlation ($r = 0.48$).

Herbs

There was a lag detection response of herb cover after restoration when measured with PP compared to LPI (Fig. 3); it follows that a large difference in estimates was noted for the fourth year after restoration where covers were estimated at 67 % with LPI compared to 17 % with PP. The herbs cover was stable in the unrestored zone with LPI showing estimated covers slightly higher than with PP (18 % compared to 14 % in the eighth year). Among herbs, the sedge *Eriophorum vaginatum* (Cotton-grass) was the most abundant, increasing steadily after the second year post-restoration to reach 51 % the sixth year with LPI method and to 35 % with PP (Fig. 4). With PP, the cover decreased to 20 % eight year post-restoration, a decrease not perceived with LPI. In the unrestored zone, the values stayed low and stable with the two methods (under 5 %).

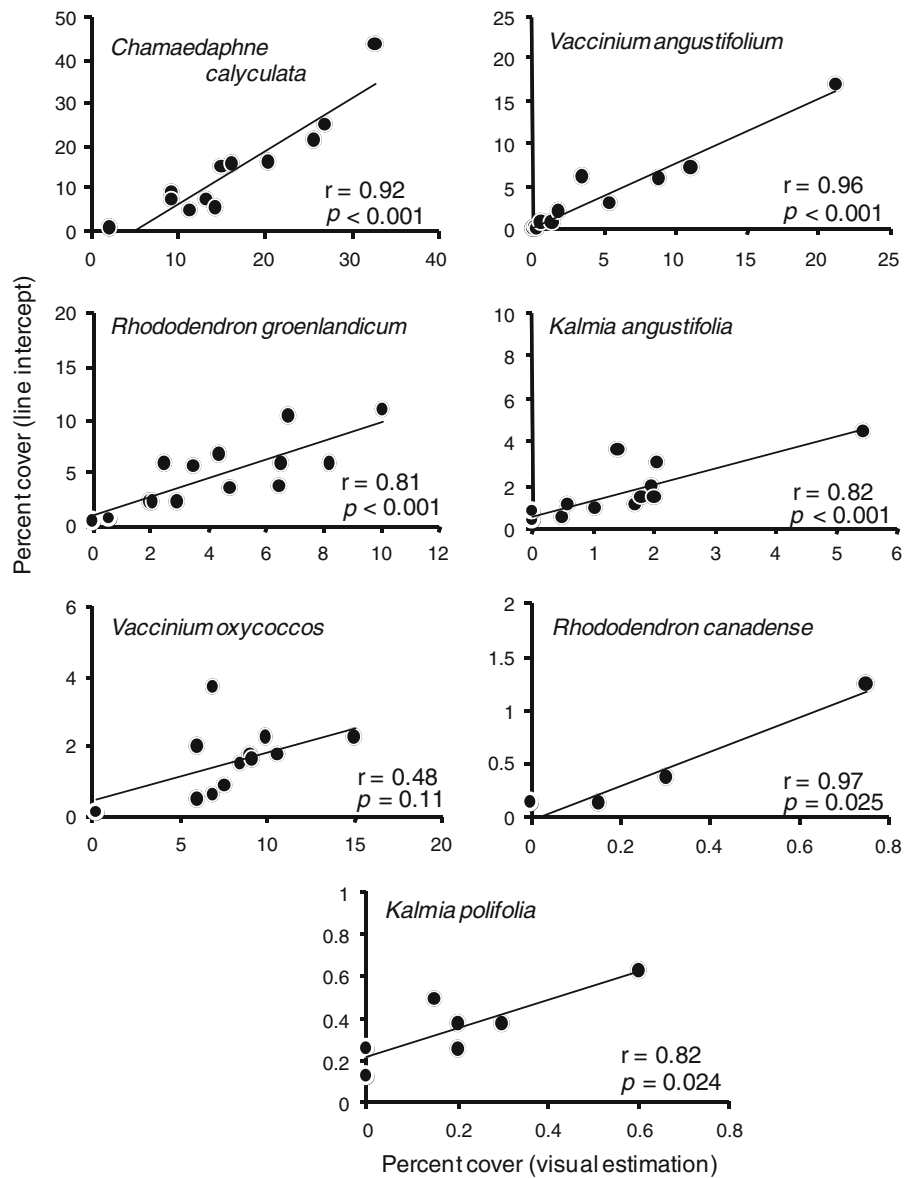
Trees and shrubs

Estimated covers of trees and shrubs remained below 22 % for both the restored and unrestored zone (Fig. 3) and the two methods gave similar results, although cover was estimated to be 22 % with LPI compared to 6 % with PP the last year of survey in the unrestored zone.

Sampling effort in the restored zone

When reducing sampling effort, the variance associated to the mean of frequencies of occurrence for each plant group increased rapidly when the fraction of lines was below 40 % of the initial number of lines (Fig. 6). The pattern was rather similar for all plant groups and for all years. The very low variances result

Fig. 5 Complementary method for estimating the cover of ericaceous species: comparison between visual estimation within plots and measurements done with a LI method. Calculations were made only for species found with sufficient number of individuals; r = Pearson's correlation coefficient



from the low deviation among the bootstrapped samples and from the low frequencies of occurrences of the majority of the species within the plant group.

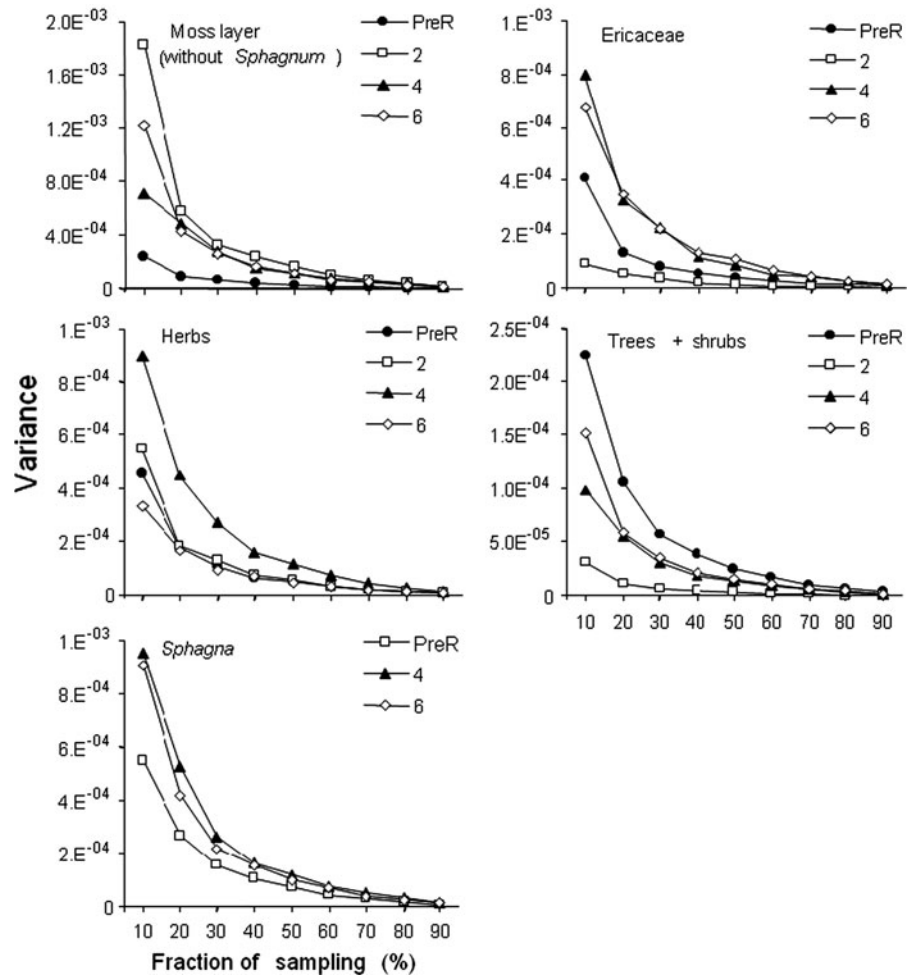
Discussion

Comparison of methods

The findings of monitoring, over a temporal sequence of 9 years (including the year pre-restoration),

highlight how LPI cover estimates are consistently higher than visual cover estimates obtained with a PP method. This was the case for every plant group or species, and nearly every year sampled. Other studies conducted in different types of ecosystems also reported over-estimation of plant cover by line or point methods (Kercher et al. 2003; Korb et al. 2003). A well-known explanation for that is the size of the point, i.e. the diameter of the rod that hits the plant: the larger the size of the point is, the higher the cover estimation is. Theoretically speaking, point intercept

Fig. 6 Variances of plant group cover after down-sampling the number of transects from the LPI method (from 90 to 10 %). Points are the variances calculated from the mean of 1,000 bootstrap samples. Analysis were performed with data from the restored zone, the year pre-restoration (1999) and 2, 4 and 6 years post-restoration



methods are supposed to be dimensionless, but for practical evidence, any pin used has a dimension (4–6 mm in diameter in our case).

A closer analysis by plant group allows a better understanding on the confidence towards the estimates or on how the different methods detect change of vegetation during succession in peatlands. For the moss layer, comparisons done only on the second or sixth year post-restoration (Fig. 3) conclude to a close similarity in the estimations of the mosses abundance. But this is not the same picture for the third to fifth year. With the “moss layer transfer technique” used for restoring cut-over bog in North America, carpets of *P. strictum* are actively favoured by phosphorus fertilisation in order to protect soil against frost heaving (Groeneveld et al. 2007). Hence, *Polytrichum* patches dominate in the first 2 years in the form of dense carpets (Fig. 7a) with small imbedded

developing *Sphagnum* diaspores. One has to tear apart the *Polytrichum* moss carpet to detect the *Sphagnum*, which at the early stage post-restoration (1–3 years) are mostly present as individuals but not yet forming carpet or cushion. At that stage, we thus barely see the *Sphagnum* moss capitula from above during visual estimation but we do notice the branches and the stems touching the tip of the pin when a closer look is taken with LPI. Consequently, the *Sphagnum* are underestimated with PP method in the first years post-restoration while they are hidden in the sub-canopy of the dense *Polytrichum* mosses. When the *Sphagnum* mosses succeed to dominate the carpet (usually >5 years post-restoration), two observations can be made: (1) When the *Sphagnum* capitula are fully developed and prominent with their colour, they are well detected by both methods and (2) with the development of the dominant *Sphagnum* carpet, we

observe the reverse trend in term of the detection of the *Polytrichum* mosses where they are most likely overestimated in abundance by LPI method (Fig. 4). As the *Sphagnum* mosses take over the *Polytrichum* carpet, it is the latter species that becomes individualised and thinner (Fig. 7b). Thus, the detection of moss species is favoured by the LPI method when the mosses are individuals, well dispersed, in low abundance and when there are differences in height between species.

Based on the moss carpet development, it appears that small, thin, elongated and individual plant structures will be better detected by LPI whereas PP would give better estimates of the abundance once the plants are clustered. The study of the Ericaceae also supports this conclusion. (1) Most ericaceous species are very small when they first start from seeds forming only one tiny unbranched stem and remain this way several years until self-thinning occurs and biggest shrubs dominate (Klein et al. 2005). These little stems are embedded within the moss carpet early in the plant succession post-restoration and barely noticeable unless a closer investigation is done such as with LPI. The gap between both methods after the fourth year post-restoration was mainly due to species such as *C. calyculata* and *V. oxycoccus*. With *C. calyculata* (Fig. 4), cover is overestimated by LPI method compared to the range of cover seen in natural peatlands of the region and this overestimation is also perceived in the field (Fig. 7c). (2) *V. oxycoccus* forms thin, elongated stolons running on the surface conducive to overestimation. Even if this species recovers quickly post-restoration, most likely by vegetative means, it does not really cover 40 % (as estimated by LPI) of the ground as observed in the field (Fig. 7d). In this case, PP estimates appears more in line with natural abundance of the reference ecosystem (Fig. 4). Still, the remaining discrepancy (as not all is explained by *C. calyculata* and *V. oxycoccus* differences) between the estimated cover by LPI or PP for bigger shrubs could come from the evaluation by category (modified Braun-Blanquet scale) as used for PP in this study. On Fig. 3 with the Ericaceae for unrestored PP, one can notice a plateau around 8 % for years 2–4 and a second plateau around 18 % for years 5–8, corresponding to the 10–25 % class cover of Braun-Blanquet scale: then estimates of PP will tend to be in greater accordance with LPI estimates once it falls in category 3 = 26–50 % with a median of 40 %.

The measurements of ericaceous shrub cover with the LI method (Fig. 5) also give insights on the errors of estimation of each monitoring method caused by the shape of the shrubs. The plots were surveyed at 28 years (unrestored) and 8 years (restored) post-recolonised sites where shrubs were relatively well developed (more than 7 years old). The correlations indicate that direct visual estimation (from PP) would give estimates closer to observation except for *V. oxycoccus*. Again, the accuracy of the visual estimates of abundance is greater for plants forming clumps, patches or relatively homogeneous carpets than for thin, elongated, creeping structures such as *V. oxycoccus*.

The behaviour of *E. vaginatum*, the main dominant herb, allows thinking that the percent cover of tussock types of plant is well evaluated by PP assessment. In the first 2–3 years post-restoration, *E. vaginatum* was the most abundant vascular plant, establishing to the extent of fearing a serious cotton-grass invasion which would impede the establishment of a moss carpet (Fig. 7e). With the development of the thick moss carpet (>25 cm), tussock became swamped in and appeared more like loose single leaves surrounded by mosses (Fig. 7f). Over time, these thin, long and elongated leaves did become overestimated by the use of LPI method which was susceptible to touch plants with extended but loose leaf architecture. Throughout our numerous visits to the research site, we noticed the overall decline of the *E. vaginatum* tussock abundance lately as is often observed to be a natural pattern in spontaneously colonised cut-over peatlands (Lavoie et al. 2005).

Choice of methods for restoration success assessment

The choice of a monitoring method to assess success of a restoration project will depend on goals and financial means. In terms of logistic, the two methods differed in their sampling efforts. In this study, LPI took 42 person-days to survey the entire site, while it took 24 person-days with the PPs. In addition, data treatment is more time-consuming with LPI. Similarly, Carlsson et al. (2005) had concluded that it took on average five times longer to complete frequency analyses compared to visual estimation of percentage cover analyses. But Line methods are easy to set up, rapid and do not involve subjective visual estimates of



Fig. 7 Illustrations of the temporal evolution of the plant cover at BDB restored peatland. **a** Relatively uniform dense carpet of *P. strictum* 2-years post-restoration. **b** *Sphagnum rubellum* (red capitula) overtopping the slender tips of *P. strictum* (green tips). **c** An oblique view of the site 4-years post-restoration

plant cover (Myers and Shelton 1980). A large sampling effort is required to adequately represent the population or site investigated and to hit the infrequent species (Mueller-Dombois and Ellenberg 1974; Stohlgren 2007). Apparently the use of at least 200 points per 1,000 m² would yield similar diversity estimates between LPI and PP in grassland systems (Leis et al. 2003). Our sampling consisted of 100 points per 1,000 m² which led to discrepancies with the PP method. Still, we showed that the sampling effort of LPI can be largely reduced by decreasing the number of transects without affecting much cover estimations. Indeed, the variances associated to the cover estimates only increased after a diminution of 50–60 % of the initial number of transects (for all strata; Fig. 6). Using a category scale for PP ensures a greater uniformity in the estimations between years and the different observers but a drawback is the lag response (frog jumps) when reaching values closed to a change of category.

If the goal is to assess the success of the restoration actions, or to simply verify that all the different species groups and biodiversity are establishing adequately in

where one observed a general dominance of the herbs within the vascular plant group. **d** *V. oxycoccus* growth form over a carpet of mosses post-restoration. **e** Extent of *E. vaginatum* cover 2 years post-restoration. **f** *Sphagnum* mosses taking over a tussock of *E. vaginatum*. (Color figure online)

the young stages post-restoration (<5 years post-restoration), LPI should be favoured over PP for several reasons: (1) LPI gives a more complete picture of the presence of the species all over the site because of its comprehensive systematic spatial distribution (Floyd and Anderson 1987). This can allow identifying areas where adaptive management might be needed, e.g. if particular species are missing, or if particular areas remain bare. Indeed extensive area sampling techniques is most effective at capturing overall species composition and rare and exotic species (Korb et al. 2003); (2) LPI should be favoured when small changes are critical (Carlsson et al. 2005); (3) small, thin or elongated species are common in early stages of recolonisation and would be neglected by PP; and (4) the presence of straw mulch over the vegetation in the first years (because of the restoration method) can be a hindrance for visual estimates of cover over a surface, but do not affect LPI. Nevertheless, one has to be careful not to translate these presences (or frequencies) into cover in a blind and automatic way as LPI do overestimates the cover of thin species.

If the goal is to assess the vegetation trajectory against reference regional systems, PP could be installed over the site 5–6 years post-restoration. Indeed, at this stage, the moss carpets are better developed and it is easier to estimate covers in particular for *Sphagnum* mosses, key ecosystem-engineer species. Ericaceous shrubs are bigger and more mature facilitating the estimation of their cover visually. Furthermore, it is after few years post-restoration that we are interested to compare the restored site with reference ecosystems, which are more easily and often sampled with quadrats (% cover: Gignac et al. 2004) in natural peatlands than with a LPI method. In peatlands, quadrat size of less than 1 m² is rather the norm to evaluate species abundance at the species level (0.38 m² in this study). It has been pointed out that the accuracy of the visual method is reliable for plot size under 1 m² because larger areas are difficult to mentally integrate (Dethier et al. 1993). The complementary sampling study done on the Ericaceae shows that a good confidence can be given to PP to assess plant community with mature shrubs. If a category scale of cover as used in this study is chosen, a monitoring frequency of 3–5 years should prove most informative when cost-efficiency is a goal.

If the scale of a given restoration project is in the order of hundreds of hectares, then relatively fine scale method of LPI would not be a primary choice. At a medium scale (up to ca. 300 ha), PP could be used within a stratified design (for example one PP by homogeneous sector estimated visually) but the reliability of the sampling would need to be verified by using for example indices of similarities or analyses of Beta-diversity within and among sectors. At even larger scale (>300 ha), satellite imagery could be investigated as a good amount of vegetation structure and biodiversity can be monitored by remote sensing for wetlands and peatlands (Poulin et al. 2002; Sun et al. 2011).

Assessment of the success of Bois-des-Bel peatland restoration project: vegetation

Rocheport (2000) highlighted the importance of re-establishing a moss layer in restored peatlands, hence returning the derelict land to a peat accumulating system. The restoration procedures succeeded particularly well in bringing back key moss species such as *Sphagna* since their cover reached 75 % of the values

of regional natural sites. We believe that *Polytrichum* acted as a nurse-plant in helping the establishment of the *Sphagnum* species as evidenced by the mutual replacement of the species (Groeneveld et al. 2007). The ericaceous covers are most likely overestimated by LPI method when compared to the reference ecosystem (Fig. 3), but ericaceous plants do establish in great numbers to self-thin their populations afterwards (Klein et al. 2005). The cover of herbs was much higher in the restored peatland than in the reference ecosystem, mainly due to the high abundance of the cotton-grass (*E. vaginatum*). As the *Sphagnum* carpet will increase in cover and thickness, the herb cover will decrease as described in Robert et al. (1999) in the natural succession stages of spontaneously recolonised block-cut peatlands. Overall, based on PP assessment, most life form groups of the restored peatlands are developing a structure similar to the regional reference ecosystem 8 years post-restoration with the herb group being still most dissimilar. Indeed, when analyzing the temporal evolution of the different key peatland plant components, several are within the range of regional abundance values (e.g. *C. calyculata*, *V. oxycoccus*) or moving positively towards it such as *Sphagnum* cover, a key peat-accumulating plant group. Because peatland ecologists define the bogs of the boreal biome by the dominant presence of *Sphagnum* mosses (Wieder and Vitt 2006), we judged that a score of 75 % can be given to the BDB site in term of success towards the reference ecosystem.

Conclusion

LPI method gives higher values of cover when compared to abundances estimated by PPs. The discrepancy is greatest when species are well dispersed individuals, rather linear such as single acrocarpous mosses, young developing stem of shrubs or long graminoid leaves, present in low abundance. Thus the choice of the method to track vegetation changes should be done according to the vegetation structure of the ecosystem under study and the main group of interest to monitor. Key abundant plants are well tracked by visual cover estimation of PPs. Rare and species in low abundance are better detected by LPI methods. Whenever possible it is better to estimate cover values to the nearest percentage,

instead of using cover class, limiting the frog jump effect in reporting. On the investment side, LPI is more expensive in money and time of analysis but better at detecting the infrequent species. It is preferable to choose a systematic LPI method when one wants to assess spatially the impact of restoration actions in the early stages post-restoration. Mostly for restoration projects starting with close to no ground vegetation at all, LPI can help to evaluate if adaptive management is needed for the failure of on some sectors of the site.

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References

- Andersen R, Francez A-J, Rochefort L (2006) The physico-chemical and microbial status of a restored bog in Qu ebec: identification of relevant criteria to monitor success. *Soil Biol Biochem* 38:1375–1387
- Anderson LE (1990) A checklist of *Sphagnum* in North America North of Mexico. *Bryologist* 93:500–501
- Anderson LE, Crum HA, Buck WR (1990) List of the mosses of North America North of Mexico. *Bryologist* 93:448–499
- Belsky AJ (1985) Long-term vegetation monitoring in the Serengeti National Park, Tanzania. *J Appl Ecol* 22:449–460
- Bonham CD (1989) Measurements for terrestrial vegetation. Wiley-Interscience, New York
- Brodo IM, Duran Sharnoff S, Sharnoff S (2001) Lichens of North America. Yale University Press, New Haven
- Canfield RH (1941) Application of the line interception method in sampling range vegetation. *J For* 38:388–394
- Carlsson ALM, Bergfur J, Milberg P (2005) Comparison of data from two vegetation monitoring methods in semi-natural grasslands. *Environ Monit Assess* 100:235–248
- Dethier MN, Graham ES, Cohen S, Tear LM (1993) Visual versus random-point percent cover estimations: ‘objective’ is not always better. *Mar Ecol Progr* 96:93–100
- Efron B, Tibshirani RJ (1993) An introduction to the bootstrap. Chapman & Hall, Boca Raton
- Egan D (2001) The historical ecology handbook: a restorationist’s guide to reference ecosystems. Island Press, Washington
- Flora of North America Editorial Committee (1993+) Flora of North America North of Mexico. Flora of North America Editorial Committee, New York
- Floyd DA, Anderson JE (1987) A comparison of three methods for estimating plant cover. *J Ecol* 75:221–228
- Gignac LD, Gauthier R, Rochefort L, Bubier J (2004) Distribution and habitat niches of 37 peatland Cyperaceae species across a broad geographic range in Canada. *Can J Bot* 82:1292–1313
- Goslee SC (2006) Behavior of vegetation sampling methods in the presence of spatial autocorrelation. *Plant Ecol* 187:203–212
- Graf MD, B erub e V, Rochefort L (2012) Chapter 12: restoration of peatlands after peat extraction: impacts, restoration goals, and techniques. In: Vitt DH, Bhatti JS (eds) Restoration and reclamation of boreal ecosystems. Cambridge University Press, Cambridge, pp 259–280
- Groeneveld EVG, Mass e A, Rochefort L (2007) *Polytrichum strictum* as a nurse-plant in peatland restoration. *Restor Ecol* 15:709–719
- Jonasson S (1988) Evaluation of the point intercept method for the estimation of plant biomass. *Oikos* 52:101–106
- Kercher SM, Frieswyk CB, Zedler JB (2003) Effects of sampling teams and estimation methods on the assessment of plant cover. *J Veg Sci* 14:899–906
- Klein E, Berg EE, Dial R (2005) Wetland drying and succession across the Kenai Peninsula Lowlands, south-central Alaska. *Can J For Res* 35:1931–1941
- Korb JE, Covington WW, Ful e PZ (2003) Sampling techniques influence understory plant trajectories after restoration: an example from Ponderosa pine restoration. *Restor Ecol* 11:504–515
- Lavoie C, Zimmermann C, Pellerin S (2001) Peatland restoration in southern Qu ebec (Canada): a paleoecological perspective. *Ecoscience* 8:247–258
- Lavoie C, Marcoux K, Saint-Louis A, Price JS (2005) The dynamics of a cotton-grass (*Eriophorum vaginatum* L.) cover expansion in a vacuum-mined peatland, southern Qu ebec, Canada. *Wetlands* 25:64–75
- Leis SA, Engle DM, Leslie DM Jr, Fehmi JS, Kretzer J (2003) Comparison of vegetation sampling procedures in a disturbed mixed-grass prairie. *Proc Okla Acad Sci* 83:7–15
- Levin SA (1992) The problem of pattern and scale in ecology. *Ecology* 73:1943–1967
- Londo G (1976) The decimal scale for relev es of permanent quadrats. *Vegetatio* 33:61–64
- Lucchese M, Waddington JM, Poulin M, Pouliot R, Rochefort L, Strack M (2009) Organic matter accumulation in a restored peatland: evaluating restoration success. *Ecol Eng* 36:482–488
- Mazerolle M, Poulin M, Lavoie C, Rochefort L, Desrochers A, Drolet B (2006) Animal and vegetation patterns in natural and man-made bog pools: implication for restoration. *Freshw Biol* 51:333–350
- Mueller-Dombois D, Ellenberg H (1974) Aims and methods of vegetation ecology. Wiley, New York
- Myers LW, Shelton RL (1980) Survey methods for ecosystem management. Wiley, New York
- Parker VT, Schile LM, Vasey MC, Callaway JC (2011) Efficiency in assessment and monitoring methods: scaling down gradient-directed transects. *Ecosphere* 2(99):1–11

- Petrone RM, Waddington JM, Price JS (2003) Ecosystem-scale flux of CO₂ from a restored vacuum harvested peatland. *Wetlands Ecol Manag* 11:419–432
- Poulin M, Careau D, Rochefort L, Desrochers A (2002) From satellite imagery to peatland vegetation diversity: how reliable are habitat maps? *Conserv Ecol* 6:16. Online <http://www.consecol.org/vol6/iss2/art16>
- Poulin M, Andersen R, Rochefort L (2012) A new approach for tracking vegetation change after restoration: a case study with peatlands. *Restor Ecol*. doi:10.1111/j.1526-100X.2012.00889.x
- Robert EC, Rochefort L, Garneau M (1999) Natural revegetation of two block-cut mined peatlands in eastern Canada. *Can J Bot* 77:447–459
- Rochefort L (2000) *Sphagnum*—a keystone in habitat restoration. *Bryologist* 103:503–508
- Shantz MA, Price JS (2006) Characterization of surface storage and runoff patterns following peatland restoration, Quebec, Canada. *Hydrol Process* 20:3799–3814
- Society for Ecological Restoration International Science & Policy Working Group (SER) (2004) *The SER International Primer on Ecological Restoration*. Society for Ecological Restoration International, Tucson. www.ser.org
- Stohlgren TJ (2007) *Measuring plant diversity: lessons from the field*. Oxford University Press, New York
- Sun Z, Chang N-B, Opp C, Hennig T (2011) Evaluation of ecological restoration through vegetation patterns in the lower Tarim River, China with MODIS NDVI data. *Ecol Inform* 6:156–163
- Waddington JM, Warner KD (2001) Atmospheric CO₂ sequestration in restored mined peatlands. *Ecoscience* 8:359–368
- Wieder RK, Vitt DH (2006) *Boreal peatland ecosystems*, vol 188. Springer Ecological Studies Series, Berlin
- Zedler JB (2007) Success: an unclear, subjective descriptor of restoration outcomes. *Ecol Restor* 25:162–168